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Foraminiferal Biostratigraphy and Paleoenvironmental Study of the Maastrichtian to Early Eocene Sediments of Y-Well Offshore Benin, Dahomey Basin

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Abstract

Y-well located within Block 1 of Seme Field, shallow offshore Benin Basin have been investigated, using foraminifera microfossils, in order to establish the proper understanding of its stratigraphy and the paleoenvironment of deposition for its sedimentary successions. The well penetrated mainly shale sediments with some intercalations of sandstone having a total thickness of approximately 2250 m. Twenty shale samples were selected and processed for foraminifera study.

Result of the foraminifera analysis reveal abundantly rich and diverse assemblages of planktic and benthic foraminifera species. 134 foraminifera species were recovered, 112 (83.6%) of which are calcareous and 22 (16.4%) of which are arenaceous. Of the calcareous forms, 91 species (81.2%) are benthics while 21 species (18.8%) are planktics. Based on the occurrence of some short stratigraphic ranged marker species, the investigated section of the Y-well is sub-divided into three foraminifera biozones. These include the *Haplophragmoides excavata* zone (Earliest Eocene), *Eponides pseudoelevatus* zone (Latest Paleocene to Earliest Eocene) and an Undiagnostic zone (which is invariably dated Late Maastrichtian-Paleocene).

Planktic-benthic ratio, agglutinated-calcareous foraminifera ratio, fisher's diversity index (< 5) and the epifaunal - infaunal ratio of the foraminifera species were used as pointers for paleoenvironmental interpretation. The sediments were deposited in a brackish hyposaline and nearshore shelf sea with water salinity ranging between 0 - 32‰, in a neritic to upper bathyal environment.

Keywords: Dahomey Basin, Early Eocene, Foraminifera biostratigraphy, Maastrichtian, Paleobathymetry, Paleoenvironment, Seme Field.

Introduction

The Benin (Dahomey) Basin is a laterally extensive, marginal sag Basin located in West Africa along the Gulf of Guinea. It extends from Ghana, through Togo, Benin Republic to south-western Nigeria (Ogbe, 1970; Klemme, 1975; Omatsola and Adegoke, 1981). The Basin evolved as a result of the crustal separation of the African and South American plates during the

Early Cretaceous which corresponds to the opening of the South Atlantic Ocean. tectonic event led to the generation of several lateral and vertical fractures such as the St. Paul, Romanche and Chain fracture zones leading to the basement fragmentation (rifting) of the African continental block, block-faulting and subsequent subsidence of rifted blocks to form series of horsts (stable blocks) and graben structures thereby creating accommodation space for sediment fill. Sedimentation in the Basin follows an East-West trend. These Cretaceous-Tertiary sediments thin out towards the east and are partially separated from the sediments of the Niger Delta Basin by the Okitipupa basement high (Omatsola and Adegoke, 1981). Y-Well penetrates Cretaceous-Tertiary sediments and it is located within Block1 in Seme Field, south of Benin Republic, shallow offshore Dahomey Basin near its border with Nigeria (Figure 1).

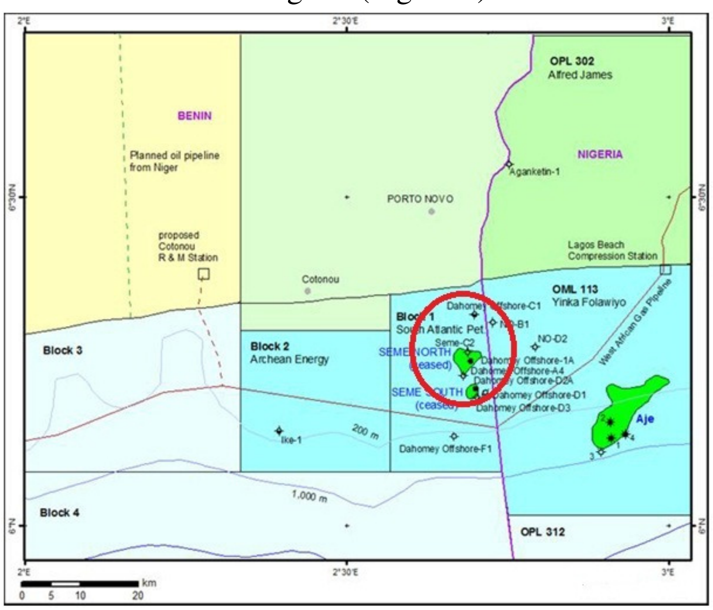

Fig. 1. Location of the study area circled in red.

The objectives of this study include the assessment of occurrence, distribution and diversity of the different species of foraminifera present in the shale sediments. Also, the construction of different biozonations for the fossils recovered from the sediments and the assessment of the ecology and dwelling environments of the different fossil forms in the sediments.

AGE		FORMATION: Ako et al,1980	FORMATION: Omatsola and Adegoke,1981		LITHOLOGY
TERTIARY	EOCENE	ILARO FM		ILARO FM	SANDSTONE
TERTIARY	PALEOCENE	OSHOSUN FM AKINBO FM		OSHOSUN FM AKINBO FM	SHALE
TERTIARY	PALEOCENE	EWEKORO FM		EWEKORO FM	LIMESTONE
CRETACEOUS	MAASTRICHTIAN	ABEOKUTA FM	ABEOKUTA GROUP	ARAROMI	SHALE
CRETACEOUS	TURONIAN		ABEOKUTA GROUP	AFOWO	SANDSTONE&SHALE
CRETACEOUS	BARREMIAN			ISE	SANDSTONE

Fig. 2. Regional geological setting of the Dahomey Basin (modified after Idowu et al., 1993).

Geology of the study area

The stratigraphy of Dahomey Basin have been discussed by several authors such as Adegoke (1969), Ogbe (1970), Billman (1976), Lehner and Ruiter (1977), Ako et al. (1980), Omatsola and Adegoke (1981), Adediran and Adegoke (1987), Okosun (1990), Idowu et al. (1993) and Adekeye and Akande (2006). Several of these authors have described five lithostratigraphic Formations covering the Cretaceous to Tertiary ages. The sedimentary Formations from the oldest to the youngest include Abeokuta Group (Cretaceous), Ewekoro Formation (Paleocene), Akinbo Formation (late Paleocene), Oshosun Formation (Early Eocene) and Ilaro Formation (Late

Eocene) (Figure 2). The detailed lithostratigraphic description of the various formations is as discussed.

The Abeokuta group represents the oldest sediments in the Dahomey basin (Figure 2). It overlies unconformably, the basement complex of southwestern Nigeria. It is subdivided by Omatsola and Adegoke (1981) lithostratigraphically into three Formations; Ise Formation, Afowo Formation, and Araromi Formation.

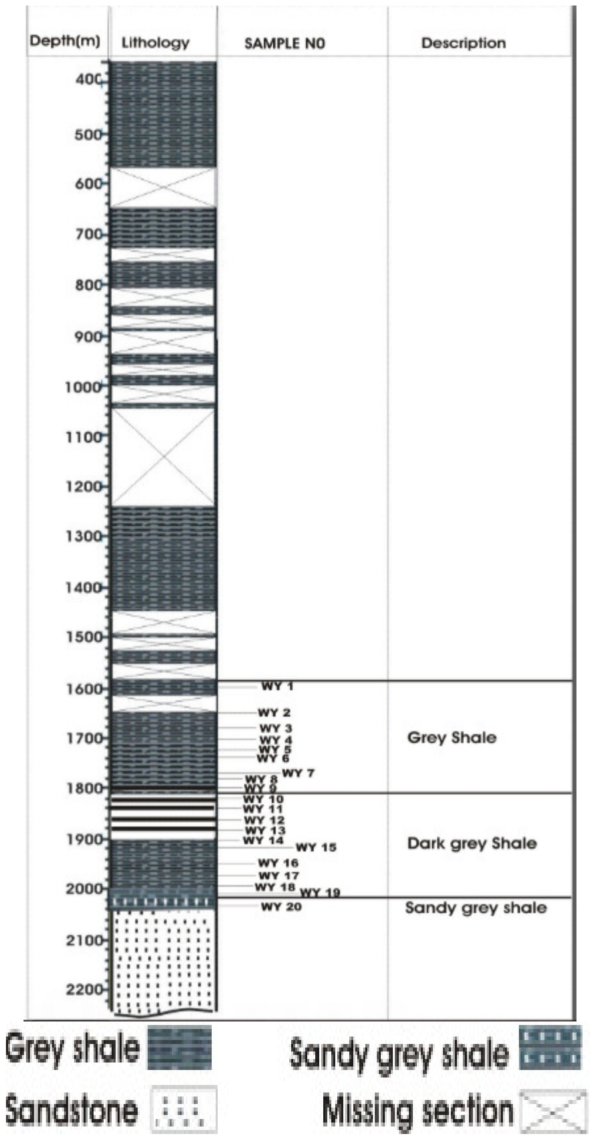

Fig. 3. Lithologic section of Well Y showing some missing sections.

Ise Formation consists of basal conglomerates overlain by coarse to medium grained sandstones and grits with interbedded kaolinitic clays. (Omatsola and Adegoke, 1981). It is dated to be of Neocomian age.

Afowo Formation dated Cenomanian-Turonian consists of coarse to medium grained sandstones with variable thickness of interbedded shales, siltstones and clays (Billman, 1976, Omatsola and Adegoke, 1981).

Araromi Formation consists of fine to medium grained sands at the base, overlain by shales and siltstones with interbeds of limestones and marls. It is Maastrichtian-Paleocene in age.

Ewekoro Formation consists of fossiliferous limestones. This Formation was dated to be lower Paleocene (Adegoke, 1969). This is uncomformably overlain by the Akinbo Formation which consists of a grey shale sequence, the base of the Formation is defined by the glauconitic bed (Ogbe, 1970). Then the Oshosun Formation and Ilaro Formation which consists of predominantly coarse sand, of the estuarine, deltaic and continental environments with rapid lateral facies changes deposited in the middle to Late Eocene regression (Adegoke, 1969; Ako et al., 1980).

Materials and Methods

Ditch cutting samples were used for this study. These were recovered from an exploratory well offshore Benin Republic courtesy of an indigenous oil company in Nigeria with the assistance of Department of Petroleum Resources (DPR). Careful lithologic description (logging) of the section was done in the laboratory with the aid of magnifying hand-lens and hydrogen chloride (HCl) to test for effervescence in order to easily distinguish carbonates from shales.

Y-well is lithologically characterized by a continuous shaly sequence of varying thicknesses with sandstone at the base. The well has a total depth of about 2250 m (Figure 3). The oldest sediment in the well is a whitish-light grey medium to fine-grained sandstone

unit of about 30 m thickness which is comformably overlain by finely laminated dark to grey shale with a thickness of about 100 m. This bed is in turn overlain by carbonaceous shale and light grey shale beds. Twenty ditch cutting samples were analyzed for foraminifera study at minimum of 10 m intervals. The processing follows standard micropaleontological preparation techniques. The unwashed ditch cutting sample is initially rinsed to remove drilling mud and dried.

The selected samples were digested in separate bowls using concentrated hydrogen peroxide (H_2O_2) and diluted with distilled water in the ratio of 1:3 (H_2O_2:H_2O). This procedure was repeated for each of the shale samples and supervised for about an hour, to check and monitor the reactions. The mixture was left for about twenty-four hours to allow complete digestion.

The digested samples were sieve-washed using 0.063 µm sieve size under running water to remove the muddy fraction. The residues were gently rinsed with water into flat plastic plates and air-dried for another 24 hours and poured into labeled plastic tubes for proper storage prior to microscopic examination. These residues were observed in little quantities per time in a tray under a binocular microscope. All the foraminifera species and accessory microfauna seen were picked, identified and counted. The fossils picked were dropped into franker slides and tagged with their depths for further identification, description and scientific classification using relevant literatures, (Bandy, 1967; Orville, 1967). The statistical data obtained was computerized using the StrataBug 2.0® software. Bar plots of the abundance and species diversity are made from which candidate Maximum Flooding Surfaces are selected. Their positions are later confirmed on the log.

Results

The well yielded abundantly rich and diverse assemblages of planktic and benthic foraminifera in the studied section with 134 species recorded. Of these, 112 species (83.6%) are calcareous, while 22 species (16.4%) are arenaceous. Of the calcareous forms, benthics accounted for 91 species (81.2%) while the remaining 21 species (18.8%) are planktics. The abundance, distribution and diversity of foraminifera species recovered are shown in Table1, while Figures 4 and 5 show some recovered species.

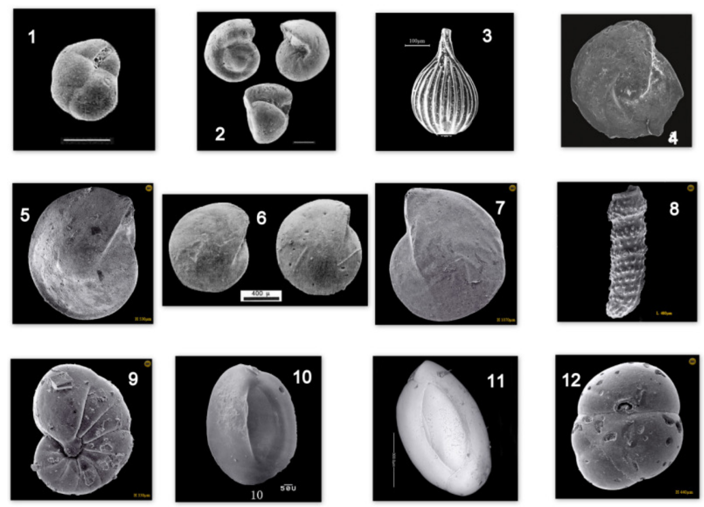

Fig. 4. Some recovered foraminifera species (Plate 1). 1. *Ammonia becarii* 2. *Anomalina* sp. 3. *Bolivina* sp. 4. *Bulimina costata* 5. *Chrysalogonium obliquatum* 6. *Cibicidoides incrassatus* 7. *Cibicidoides mundulus* 8. *Cibicidoides pseudoungerianus* 9. *Cibicidoides robertsonianus* 10. *Eggerella bradyi* 11. *Eponides* sp. 12. *Florilus atlanticus*.

Discussion

Foraminiferal biozonation

Three foraminifera biozones were recognized in the analyzed portion of the Y-well. The Cenozoic chronostratigraphic scheme of Berggren et al. (1998) and the Global Sequence Cycle Chart of Gradstein et al. (2012) were adopted for this study. The zonal names used conform to the delta-wide foraminiferal zonal scheme developed by the Stratigraphic

Committee of the Niger Delta (StratCom). The zones are characterized into three (Figure 6).

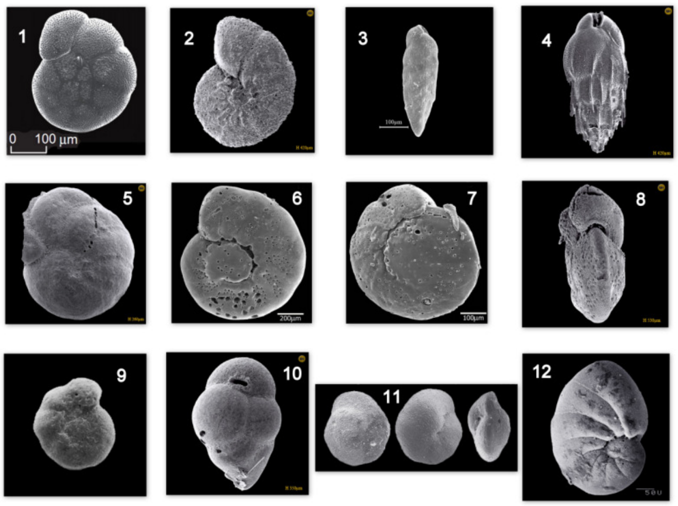

Fig. 5. Some recovered foraminifera species (Plate 2). 1. *Globocassidulina subglobosa* 2. *Gyroidinoides girardanus* 3. *Lagena* sp. 4. *Lenticulina calcar* 5. *Lenticulina cultrata* 6. *Lenticulina inornata* 7. *Lenticulina rotulata* 8. *Marginulina* sp. 9. *Nonionella auris* 10. *Quinqueloculina lamarckiana* 11. *Quinqueloculina seminulum* 12. *Sphaeroidina bulloides.*

Haplophragmoides excavata zone

Stratigraphic Interval: 1600-1820 m

Equivalent Planktic Foraminiferal zone: "Lower" P6 zone.

Age: Early Eocene (54.64 Ma and younger)

Diagnosis: This is the first zone encountered in the studied shales of the Y-well. The base of this zone is marked by the 54.64 Ma maximum flooding surface, MFS (Gradstein et al. 2012) recognized at 1820 m while the zonal top is tentatively placed at 1600 m, the depth of the first sample analyzed. The 53.65 Ma MFS of Gradstein et al. (2012) that defines the top of the zone was not recognized in the studied section of the well. The zone correlates with the "Lower" P6 Planktic foraminiferal zone of Berggren et al. (1998) and Gradstein et al. (2004). The age is Lower Eocene. The calcareous planktonic foraminifera species recovered in this zone include; *Acarinina pentacamerata, Globigerina carcoselleensis, Globigerina cryptomphala, Globigerina danvillensis,*

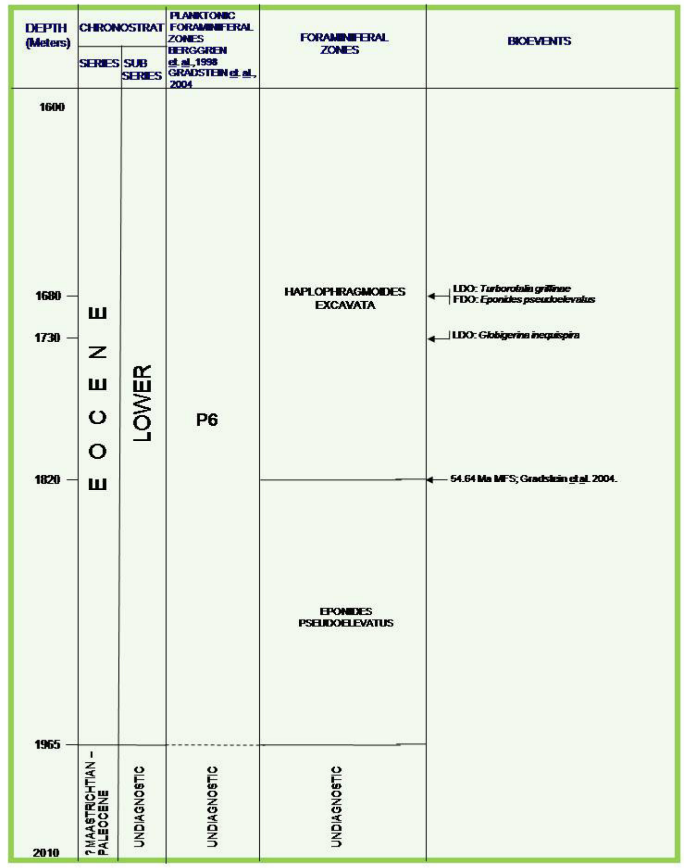

Fig. 6. Benthic foraminifera biozonation.

Globigerina friga, Planorotalites chapmani, Turborotalia cerroazulensis frontosa, Turborotalia cerroazulensis possagnoensis, Turborotalia griffinae, and *Turborotalia praecentralis.* The calcareous benthonic foraminifera species recovered in this zone include; *Ammonia becarii, Anomalinoides alazanensis, Bolivina dertonensis, Bolivina ihuoensis, Bolivina* sp., *Bolivina tenuicostata, Bulimina buchiana, Ceratobulimina pacifica, Cibicidoides incrassatus, Cibicidoides mundulus, Cibicidoides pachyderma, Cibicidoides robertsonianus, Cibicidoides ungerianus, Eggerella bradyi, Eponides africana, Eponides eshira, Hanzawaia strattoni, Heterolepa pseudoungeriana, Hopskina* sp., *Lenticulina curvisepta, Lenticulina rotulata, Melonis pompiliodes, Melonis soldanii, Nonionella danvillensis, Praeglobobulimina ovata, Quinqueloculina lamarckiana, Quinqueloculina* sp.,

Sphaeroidina bulloides, Triloculina sp.*, Uvigerina* sp.*, Uvigerina auberiana, Uvigerina gallowayi, Uvigerina proboscidea, Uvigerina sparsicostata, Valvulineria* sp.*, Valvulineria bradyana.* And the agglutinated benthonic foraminifera forms recovered in this zone include: *Ammobaculites* sp.*, Bathysiphon* sp.*, Haplophragmoides excavata, Poritextularia panamensis, Spiroplectammina carinata, Spiroplectammina wrightii,* and *Trochammina proteus.* The most abundant foraminifera species in this zone are typical of inner shelf – upper bathyal environments.

***Eponides pseudoelevatus* zone.**

Stratigraphic Interval: 1820-1886 m

Equivalent Planktic Foraminiferal zone: "Lower P6" zone.

Age: Latest Paleocene - Earliest Eocene (54.64 Ma and Older)

Diagnosis: The top of the *Eponides pseudoelevatus* zone is defined by the 54.64 Ma MFS (Gradstein et al. 2004) recognized at 1820 m, while the base is tentatively placed at 1886 m, which marks the Paleocene-Eocene boundary based on the first downhole occurence, FDO of *Archeoglobigerina blowi* at 1901 m*,* which suggests a Paleocene age, recorded within the condensed section at 1886 m. The zone correlates with the "Lower P6" Planktic foraminiferal zone of Berggren et al. (1998) and Gradstein et al. (2004). The age is Lower Eocene.

The calcareous planktonic foraminifera species recovered in this zone include; *Globigerina triculinoides* and *Morozovella aequa* while the calcareous benthonic foraminifera species recovered in this zone include; *Eponides pseudoelevatus, Eponides* sp.*, Globocassidulina subglobosa, Lagena* sp.*, Stilostomella nuttalli* and *Virgulina* sp. The most abundant foraminifera species recovered in this zone are typical of inner shelf to bathyal environments.

***Undiagnostic* zone.**

Stratigraphic Interval: 1886-2010 m

Age: ?Maastrichtian - Paleocene

Diagnosis: The top of this zone is placed at 1886 m, while the base is placed at 2010 m, depth of the last sample analyzed.

The calcareous planktonic foraminifera species recovered in this zone include; *Globigerina hoterivica, Globigerina inaequispira, Globigerina* sp.*, Globigerinoides* sp.*, Globobulimina* sp.*, Hedbergella holmdelensis.* The calcareous benthonic foraminifera species recovered in this zone include; *Anomalina* sp.*, Anomalinoides* sp.*, Bulimina costata, Bulimina minima, Bulimina* sp.*, Chrysalogonium obliquatum, Cibicides* sp.*, Cibicidoides lobatulus, Cibicidoides pseudoungerianus, Cristellaria* sp.*, Gyroidina soldanii, Gyroidinoides girardanus, Gyroidinoides longispira, Gyroidinoides neosoldanii, Heterolepa floridana, Hopskina danvillensis, Lenticulina calcar, Lenticulina cultrata, Lenticulina inornata, Marginulina hirsuta, Nodosaria pentecostata, Nodosaria* sp.*, Nonion* sp.*, Nonionella auris, Nonionella robusta, Nonionella* sp*, Oolina* sp.*, Robertinoides* sp.*, Stilostomella* sp.*, Valvulineria* sp. and the agglutinated benthonic foraminifera forms recovered in this zone include: *Alveolaphragmium subglobosum, Dentalina leguminiformis, Gravelina narivaensis, Haplophragmoides obliquicameratus, Haplophragmoides* sp.*, Karreriella siphonella, Reophax papillosus, Textularia* sp. *and Trochammina* sp. The most abundant foraminifera species recovered in this zone are typical of inner shelf – bathyal environments.

Paleoenvironmental study

Planktonic/benthonic foraminiferal ratio (P/B)

The planktonic/benthonic ratio (P/B) is a simple and easily estimated value to obtain a considerable amount of ecologic information on large scale regional environmental changes with several advantages over counts of specific or generic groupings. Generally, the planktonic/benthonic (P/B) ratios are lowest in shallow environments and increase with depth. The

foraminiferal planktonic/benthonic ratios which are used here are calculated for each sample in the Y-well. In each proposed biozone the arithmetic mean of these ratios is calculated as a standard value characterizing the stratigraphical interval covered by the biozone. The P/B foraminiferal ratios of the studied well is illustrated in Table 1, where very low P/B = 0 – 10%, low = 11 – 30%, moderate = 31 – 50%, high = 51 – 80%, and very high = 81 – 100%.

Based on P/B ratio, Murray (1991) characterized sediments of various depositional environments. The Upper continental slope is characterised by high P/B ratio > 2.33 (> 70 : < 30)%, Outer shelf (open sea) by P/B ratio of 0.67 – 2.33 (40 - 70 : 60 - 30)%, Middle shelf (open sea) by P/B ratio of 0.11 – 1.5 (10 – 60 : 90 – 40)% and Inner shelf (open sea) by P/B ratio < 0.25 (< 20 : > 80)%. The *Haplophragmoides excavata* zone has an average P/B ratio of 0.29 suggesting a middle shelf environment of deposition, while the *Eponides pseudoelevatus* zone have an average P/B ratio of 0.19 suggesting inner - middle shelf environment and the *Undiagnostic* zone with an average P/B ratio of 0.04 suggesting an inner shelf environment (Table 1).

Arenaceous/calcareous benthonic foraminiferal ratio (A/C)

The agglutinated (arenaceous) benthonic forms can occur in different environments ranging from very shallow marine neritic to abyssal environments. A similar methodology to determine planktonic/benthonic ratio (P/B) is followed to establish the arenaceous/calcareous ratio (A/C). Low A/C ratio ranges from 0 – 0.25, moderate = 0.26 – 0.50 and high > 0.50. The distribution patterns of the arenaceous/calcareous foraminiferal ratios are shown in Table 1. Saint-Marc (1986) stated that the dominance of calcareous foraminifers indicates deposition largely above the calcium carbonate compensation depth (CCD line), in an area high in calcium carbonate, well oxygenated and characterized by normal salinity and/or high temperature as is the case in this study. Conversely, high A/C ratio suggests deposition below the CCD.

The calculated A/C ratios for each studied biozone in Y- Well are as follows: for the *Haplophragmoides excavata* zone, 0.41 (moderate), the *Eponides pseudoelevatus*, 0.15 (low) and the *Undiagnostic* zone, 0.49 (moderate).

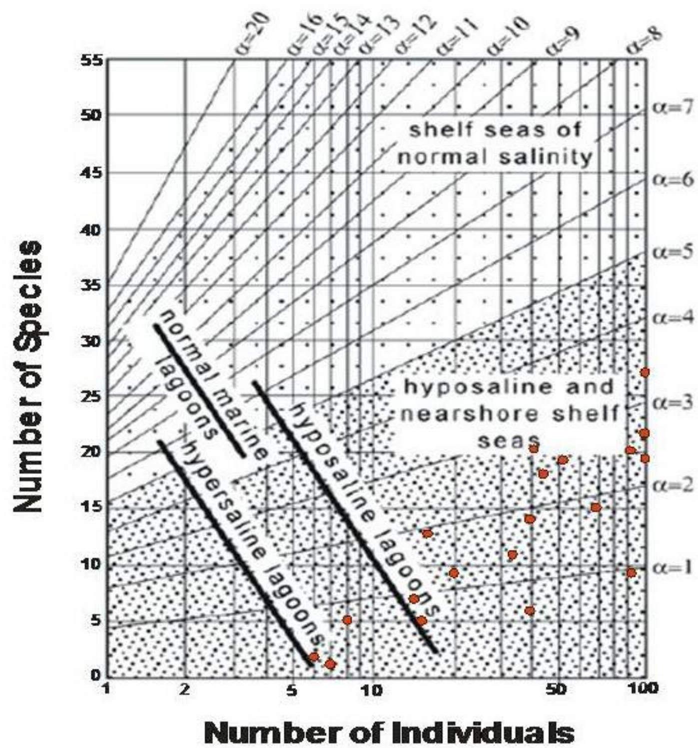

Fig. 7. Graph illustrating the Fisher's diversity index per depth for paleoenvironmental interpretation (Fisher, 1991). (majority of samples are falling in between hyposaline lagoons and near shore shelf seas environment).

Fisher's diversity index

Fisher diversity can be expressed as the total number of foraminiferal species in any sample. Generally, the number of species (diversity) increase away from the shore. Olsson and Nyong (1984) reviewed the diversity concept and stated that the diversity trends of recent benthonic foraminifera show an increase in the number of species from the near shore to the outer continental shelf, species diversity either decreases or remains the same on the continental slope, finally increasing in the abyssal realm. It is useful for

interpretation of paleobathymetry, paleosalinity and oxygenation levels at the time sediment deposition. The inner shelf is characterised by $\alpha = 1 - 5$, Outer shelf is characterized by $\alpha = 5 - 19$, the slope is characterised by $\alpha = 19 - 25$. The highest values of α indicates the lowermost slope (Murray, 1991).

According to Fisher et al. (1943) and Murray (1991), it can be calculated by: $a = n_1 : x$, where: x is a constant having values < 1, $n_1 = N (1 - x)$, and N being the number of individuals. Bulk of the shale sediments of Y-well fall within an alpha value < 5 suggesting deposition in a hyposaline and nearshore shelf sea (inner shelf) of salinity within 0 - 32‰ (Table 1, Figure 7).

Sample No.	Depth (m)	Lithology	Planktic calcareous	Benthic calcareous	Benthic Agglutinating	Total Count	Benthic Diversity	Total Diversity	%Planktics	P/B Ratio	A/C Ratio
WY1	1600	Shale	90	92	20	202	11	21	44.55	0.8	0.22
WY2	1650	Shale	16	41	16	73	29	33	21.92	0.28	0.39
WY3	1680	Shale	77	119	36	232	28	39	33.19	0.5	0.3
WY4	1700	Shale	210	560	66	836	22	29	25.12	0.34	0.12
WY5	1730	Shale	41	142	15	198	30	37	20.71	0.26	0.11
WY6	1740	Shale	21	94	20	135	24	29	15.56	0.18	0.21
WY7	1770	Shale	6	69	9	84	18	20	7.14	0.08	0.13
WY8	1780	Shale	7	40	4	51	16	21	13.73	0.16	0.1
WY9	1800	Shale	1	7	15	23	6	8	4.35	0.05	2.14
WY10	1820	Shale	10	44	5	59	20	23	16.95	0.2	0.11
WY11	1840	Shale	5	15	2	22	9	12	22.73	0.29	0.13
WY12	1862	Shale	2	16	2	20	8	8	10	0.11	0.13
WY13	1886	Shale	5	20	0	25	9	13	20	0.25	0
WY14	1901	Shale	23	53	6	82	21	26	28.05	0.39	0.11
WY15	1920	Shale	1	17	2	20	15	16	5	0.05	0.12
WY16	1945	Shale	4	40	17	61	11	13	6.56	0.07	0.43
WY17	1965	Shale	1	6	5	12	5	6	8.33	0.09	0.83
WY18	1990	Shale		8	3	11	7	7	0	0	0.38
WY19	2010	Shale	1	34	9	44	14	15	2.27	0.02	0.26

Table 1. Foraminifera species abundance, diversity, planktic-benthic (P/B) ratio, arenaceous-calcareous (A/C) ratio.

Paleoecology of selected genera

The modes of life for foraminiferal species are classified as epifaunal (living on the sediment surface or other substrates) and infaunal (living within the sediment). Salinity is subdivided into brackish (0 - 32‰, hyposaline), marine (32 - 37‰, normal marine) and hypersaline (> 37‰) while the temperature of the bottom water are classified as cold, temperate and warm (Murray, 1991). In terms of environment, the shelf is restricted to a water depth of 0 to 180 m, the bathyal region to water depth between 180 to ~ 4000 m and abyssal depths greater than ~ 4000 m (Murray, 1991).

The *Haplophragmoides excavata* zone is essentially dominated by the occurrence of *Bulimina* sp., *Globocassidulina* sp., *Melonis* sp., and *Nonionella* sp. which serve as pointers to prevailing paleoecological conditions as at the time of sediment deposition (as shown in Table 2). These four species are infaunal; they typically live in normal marine shelf-bathyal environments with 32 – 37 ‰ water salinity under cold to temperate temperature condition. With the exception of *Nonionella* sp. which thrives under temperate to warm water condition in environments ranging to upper bathyal. *Bulimina* sp. can also be found in inner shelf environments while *Melonis* species prefer temperature conditions generally < 10◦C. The *Eponides pseudoelevatus* zone is also dominated by the abundant occurrence of *Bulimina* sp. and *Globocassidulina* sp.; while the *Undiagnostic* zone is dominated by the abundant occurrence of *Bulimina* sp., *Nonionella* sp. and *Globobulimina* sp. which are all infaunal.

Oxygenation level using epifaunal-infaunal ratio

Infaunal mud dwellers are adapted to oxygen-depleted environments. Thus, the ratio of epifaunal to infaunal genera may reflect the degree of oxygenation.

In this study, the dominance of calcareous benthic foraminifers and the relative abundance of epifaunal over infaunal forms, with some planktonic species suggest an oxic bottom-water condition, and are therefore interpreted to represent oxic environments for the deposition of the shales (Table 2). The dissolved oxygen level could be established by the presence of definite genera in the assemblage. For example *Bolivina, Bulimina, Cyclammina, Haplophragmoides, Bathysiphon* flourish in low oxygenated environment (Boltovskoy and Wright in Ujetz, 1996).

Planktic
Benthic
Agglutinated

			Infaunal													Epifaunal														
Sample No.	Depth (m)	Lithology	*Ammobaculies sp.*	*Bathysiphon sp.*	*Bulimina sp.*	*Buliminella sp.*	*Eggerella sp.*	*Globobulimina sp.*	*Globocassidulina sp.*	*Haplophragmoides sp.*	*Melonis sp.*	*Nonion sp.*	*Nonionella sp.*	*Reophax sp.*	Total Infaunal	*Alveolophragmium sp.*	*Cibicides sp.*	*Cibicidoides sp.*	*Eponides sp.*	*Gyroidina sp.*	*Hanzawaia sp.*	*Heterolepa sp.*	*Karreriella sp.*	*Lenticulina sp.*	*Planulina sp.*	*Quinqueloculina sp.*	*Recurvoides sp.*	*Textularia sp.*	*Triloculina sp.*	Total Epifaunal
WY1	1600	Shale											20		20						10		10	10		10				40
WY2	1650	Shale	2		4				2						8	2		8			2		4	4	2		2	2		26
WY3	1680	Shale			16										16				16				4			4	4			28
WY4	1700	Shale			20										20			20	40	20						20				100
WY5	1730	Shale		5					3		5		10		23		5	5	14			5		10					5	44
WY6	1740	Shale					5		4		4				13			8				8	5	4		5				30
WY7	1770	Shale			3				2						5		2	1				2								5
WY8	1780	Shale			2				2				2		6			4		2				2		2			2	12
WY9	1800	Shale					2						2		4				3											3
WY10	1820	Shale			6										6			2					2	2		2			2	10
WY11	1840	Shale			3										3															0
WY12	1862	Shale			2				3						5									2			2			4
WY13	1886	Shale													0									2						2
WY14	1901	Shale			2			4	2			2	2		12		2	4		2		2		6						16
WY15	1920	Shale			2								2		4		3	1						1						5
WY16	1945	Shale			2										2		3	3					2					2		10
WY17	1965	Shale													0	3												1		4
WY18	1990	Shale												1	1															0
WY19	2010	Shale			3	2							2		7		2			2			3							7

Table 2. Total epifaunal - infaunal abundance of planktic, benthic and agglutinated foraminifera species in the shales.

The presence or absence of ornamentation is also influenced by the oxygen levels. For example the presence of ornamented individuals of *Bulimina, and Globobulimina also* suggest a low dissolved oxygen level. Species diversity is also informative for the dissolved oxygen levels. Assemblages, characteristic for low oxygenated environment demonstrate low species diversity (α < 7).

Conclusion

The high recovery of marine benthonic foraminiferal species such as *Bulimina* sp., *Globobulimina* sp., *Globocassidulina* sp., *Melonis* sp. and *Nonionella* sp. across the three biozones of Y-well suggests marine depositional environment in an inner shelf to middle shelf water depth. P/B foraminiferal ratio (0 - 0.8), Fisher diversity index < 5 and other multivariate plots are also evidences which suggest deposition of the shales in an environment which ranges between brackish, hyposaline lagoon and nearshore shelf sea (0 - 32‰ salinity) at maximum water depth of about 650 m.

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